1977 Ward Wicker Soil Study

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PLUTONIUM DISTRIBUTION IN ROCKY FLATS SOIL*

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Abstract—Plutonium concentrations in Rocky Flats soil were inversely proportional to distance from the plutonium source, to depth of the sample, and to particle size of sieved soil samples Coefficients of variation ranged to more than 300%, and frequency distributions of plutonium concentrations in samples were highly skewed The plutonium distribution patterns and known characteristics of the plutonium source indicated that the mechanisms of environmental dispersion may have involved the attachment of plutonium oxide to soil particles; primary dissemination of contaminant from the source by wind, and weathering, microdispersal, and penetration into soil of deposited particles The high degree of spatial variability, in particular, suggested that the most common functional form of the contaminated soil during dissemination was probably an agglomerated particle containing many plutonium oxide and soil particles bound together

INTRODUCTION

A COSTLY fire at Rocky Flats in 1969 and later detection of off-site ^{239}Pu in soil samples (Ma70; Po72) spurred discussion of the environmental contamination problems and safety implications of the Rocky Flats installation (Jo76; Kr70; Ma70; Po72; Sh71) Further investigations indicated that the primary contaminating event was leakage from drums containing plutonium-laden cutting oil that had been stored outdoors in the southeast corner of the plant (Kr70; Po72).

Soil is the most important ecosystem compartment at Rocky Flats with regard to fraction of total plutonium contained and potential for plutonium transport (Li76) Consequently, this paper examines data from a study, begun in late 1971, of the patterns of plutonium contamination in Rocky Flats soil Specifically, this report describes (1) data on plutonium concentrations in soil, (2) the relationship of concentration to location, depth, and soil particle size, and (3) a description of the likely contamination mechanisms

The Rocky Flats (RF) installation, operated by Rockwell International for the Energy Research and Development Administration (ERDA), is located about 12 km, northwest (NW) of the nearest portions of the Denver, Colorado metropolitan area at an elevation of over 1800 m ERDA controls approximately 30 km^2 of land, most of which is used as a buffer zone to separate the public from plant production operations.

Topography of the installation is characterized by a series of flat, wind-scoured plateaux divided by five separate watercourses running roughly from west to east Rocky Flats climate is typified by strong and often gusty winds (3 7 m/sec mean) and moderate rainfall (40 cm/yr mean). Typically, the stronger winds at RF blow from the west (W) and NW, during 1975, 22% of the recorded winds were from the NW (An76). Vegetation at the installation is modified grassland. Ex-

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cept for a new buffer zone purchased in 1975, Rocky Flats land has not been significantly disturbed by man for over 25 yr. The flora and fauna have been described previously (We74; Wh73).

Data from RF air sampling station S-8 (Hu76), located about 75 m southeast of the barrel storage area, agree with information gathered by ERDA's Health and Safety Laboratory (Kr70) that identifies the barrel storage area as the source of the east-southeast contamination pattern at the site. Monthly averages of daily air samples indicated that gross alpha activity was associated with periods of known perturbation of the contaminated surface (Table 1, Fig. 1). These data indicate the time of the original plutonium dispersal and provide strong evidence that the barrel storage area was the main source of Pu contamination in the downwind ecosystem until the area was covered by asphalt in 1969.

*Table 1 Total monthly gross alpha activity in ambient air at station S-8 (75 m east of oil barrel storage area) during perturbation events of the storage area surface**

Dates	Event	Alpha activity (dis/min/m³)
7/59–9/63	No large scale leaking	0.030
1/64–1/65	Large scale leaking	0.056
1/65	Contaminated soil covered with fill	0.022
1/66	Small building added to filter contaminated oil from leaking to new drums	0.031
1/67	Drum removal activity begun	0.084
6/68	Last drums removed but high winds spread some activity	0.417
2/69	Woods burned area graded for paving	0.067
9/69	Asphalt pad completed	0.029
11/69	Four sampling wells dug through pad	0.073
4/71	Drainage ditch dug on west side of asphalt pad	0.073

*Air filter material was counted directly in a gas-flow proportional detector Data adapted from Hu76.

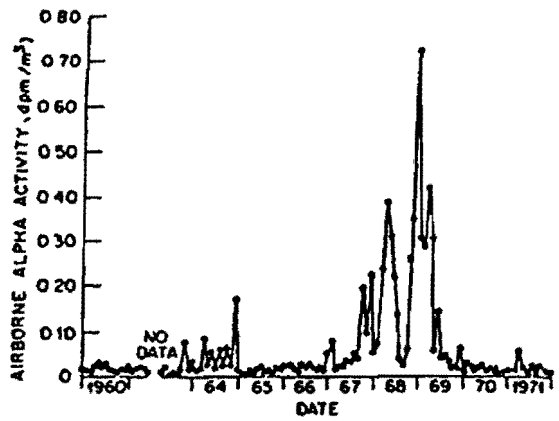

FIG 1 Monthly means of daily gross alpha activity in ambient air at station S-8 (75 m east of the oil barrel storage area) Aliquots of Gelman AE filter material were counted in a gas-flow proportional detector Data adapted from Hu76

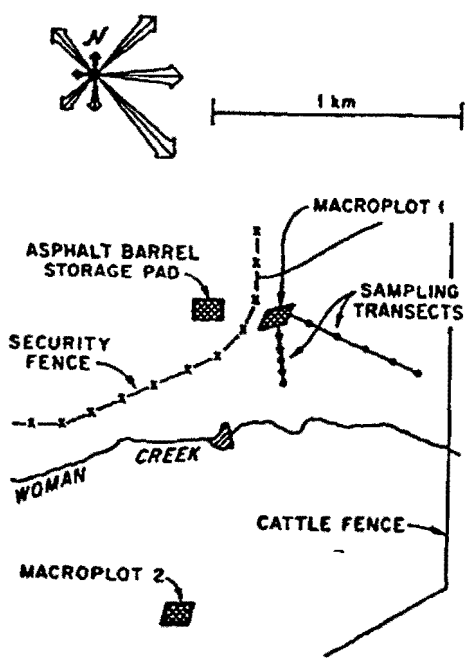

FIG 2 Schematic representative of southeast corner of Rocky Flats installation showing location of Macroplot 1 and two sampling transects in relation to barrel storage area The wind rose indicates the directions toward which the mean winds blew during 1974

METHODS AND MATERIALS

We established two macroplots for study (Fig. 2). The Macroplot 1 sampling grid covered about 0.58 ha and contained 100 microplots (grid intersections). The Macroplot 2 grid had 25 microplots and covered about 0.12 ha Macroplot 1 presumably had the highest concentrations of Pu in soil outside the security fence and had a reasonably undisturbed vegetative community Conversely, Macroplot 2, by virtue of distance, direction, and the presence of sheltering topography between the source and the macroplot, was presumed to be nearly background Vegetative communities of the two

macroplots were similar. During 1972–1974, four replicate soil samples from each 3-cm increment from 0 to 21 cm were taken at ten and five randomly chosen sample microplots (intersections) on Macroplot 1 and Macroplot 2, respectively.

We established two sampling transects: one extending 500 m east-southeast (ESE) from the eastern boundary of Macroplot 1 and the other running 250 m approximately south (S) from the southern boundary of Macroplot 1 (Fig 2). Four soil samples 0–3 cm were taken at each 100-m and 50-m interval along the ESE and S transects, respectively. Using aerial photographs, we estimated the distance east (X) to each sample location from a north–south line through the center of the asphalt pad and, similarly, the distance south (Y) from an east–west line to each sample of Macroplot 1 and the two transects.

Soil samples were air dried, and material greater than 0.5 cm in diameter was removed from the sample. After drying the samples in an oven, they were weighed and mechanically shaken on brass soil sieves with meshes ranging from 2000 to 45 μm, as listed in Table 2. The accumulation on each sieve and the underlying pan was weighed and sealed into a paper envelope.

Soil samples weighing approximately 5 g were sent to commercial laboratories (LFE Environmental, Richmond, California, and Eberline Instrument Corp., Albuquerque, New Mexico) or analysed in our laboratory LFE Environmental used concentrated hydrofluoric acid (We71) and Eberline modified a pyrosulfate fusion technique to dissolve samples (Si69) Ion exchange columns were used to remove interfering nuclides and to isolate plutonium from the samples before counting by alpha spectrometry. Chemical recovery was measured by addition of ^{236}Pu tracer to each sample (We71; Si69) Agreement between homogenized split samples sent to these laboratories was good (Li76). In our laboratory, a procedure incorporating harsh digestion with HNO_3 and HF, ion exchange, organic extraction, and liquid scintillation (LS) counting was used and had an estimated minimum detectable concentration of 0 18 dis/min/g for 5-g samples (Li76) Plutonium data are ^{239,240}Pu unless otherwise noted

RESULTS

Surface soil samples had a higher mean concentration than the samples below the surface (Table 2), and Macroplot 1 had a higher mean Pu concentration than Macroplot 2 Variations in soil Pu concentrations, with regard to depth, particle size distribution, and spatial dispersion, were large in samples from both macroplots (as great as 2 0 in Macroplot 1 and 4 0 in Macroplot 2) In one case, three adjacent soil columns (5 × 5 cm) from a 5 × 15 cm area of Macroplot 2 had mean plutonium concentrations of 1060 (column A), 11 9 (column B), and 1 26

Table 2. Mean plutonium concentrations and coefficients of variation (CV = standard deviation ÷ mean) of soil samples from two Rocky Flats macroplots. The number of samples totaled 931

Macroplot	Soil particle size range (μm)	Plutonium concentration dis/min/g [mean CV] of depth group aliquots							
		0–3 cm	3–6 cm	6–9 cm	9–12 cm	12–15 cm	15–18 cm	18–21 cm	0–21 cm
1	2000–850	1400, 2 0	300, 1 4	200 1.8	59 0.8	30 1.6	12, 0 9	4 0 0 6	3*0 3.9
	850–425	1000 0.8	270, 0 8	230 1 7	81 1.0	65 0 7	16, 0.9	12 0.5	290 1.8
	425–250	980 0.6	280, 0.8	200 1.8	66 0.5	66 0.5	29 0 8	13 0 2	300 1.6
	250–180	1000 0.5	280, 0.6	290 1 4	86 0 9	66 0.5	31 1 1	20 0 7	310 1.5
	180–150	1700 1 1	280, 0.6	230 1 7	77 0.6	310 1.6	57 0.7	14 1 1	450, 2.1
	150–75	1900, 0 7	460 0.8	230 1 4	150 0.9	120 0 7	97 1.3	24 0 9	530 1 7
	75–45	3100 0.5	700, 0.5	460 1 4	220 0.6	360 0.7	190 1 4	79, 0 6	880 1.5
	45–0	3300 1.6	400 1 1	1800 1 8	430 1.0	500 1.0	190 1.3	60 0.3	1300 2.4
	<2000	1900, 1.5	360, 0 9	990 2.8	150 1 4	190 1.6	75 1.8	27 1 1	570 2.7
2	2000–850	13 1 7	2.1, 0.9	0.8 1.6	1.2, 1.6	0 7 1.3	0 8 1.5	1.3 0.8	3.2, 3 1
	850–425	12, 1 7	1.5, 0 9	1.0 1.5	1.2, 1.6	0.8 1 4	0.9 1.6	2.7 0 6	3.2, 3.0
	425–250	30 1 9	4.5 1 1	3 0 1.2	3 4 1.6	3 2, 1.5	3 4 1.5	8.1 0 7	8.7 2.9
	250–180	59 2.3	12, 1 1	5 1 1.5	4.5 1 4	8 7 1 4	5.8 1 4	9.5 1 1	17 3.5
	180–150	110, 2.8	22, 2.0	5.8 1.3	7 0 0 9	8.2, 1 6	8.9 1 1	11 1 0	28 4 7
	150–75	150, 3.3	4.2, 1 1	3 9 1 4	3 9 1 1	4 7 1.6	6.1 1.3	7 9 0 8	31, 6.7
	75–45	340, 3.2	13, 1.0	6.7 1 4	6 0 1.2	12, 1.9	29 1 7	12, 0 9	69 6.5
	45–0	29 1.3	7 4 1 1	9 0 1 4	7 1 1.0	8 0 1 6	25 1 4	11 0.5	14, 1.6
	<2000	92, 4.6	8 1 2.1	4 5 1 6	4 2, 1.3	5.8 2.0	9.3 2.3	8 0 1 0	22, 8.4

(column C) dpm/g at the 0–3 cm depth. Differences between the three columns extended below the surface as well, but the pattern shown in the 0–3 cm depths did not hold. Virtually all of the plutonium in column A was found in the top 3 cm, the other depths being at or near background. In columns B and C, however, the majority of the plutonium was found at lower depths.

Generally, radionuclide contamination of the environment results in log-normal distributions (Wh66; Ce69; Pi75). Following that pattern, plutonium data from soil sampling were highly skewed (Sn67, $P < 0.05$). However, the natural log transformation of these data did not result in normal distributions [as judged by the Kolmogorov–Smirnov one-sample test, (Si56)], but did generally reduce the skewness for the seven depth groups from each macroplot tested

Linear, exponential, and power function regressions of Pu concentrations in the surface samples as functions of X or Y distance from the asphalt pad were calculated. The power function was significant ($P < 0.01$) and gave the best fits of the data for both curves (Figs 3 and 4) Based on a t-test (Dr66), the slope of the Y curve (Fig 4) was significantly steeper ($P < 0.05$) than the X curve (Fig. 3). Of several multiple linear regression models attempted, the one accounting for the largest amount of the total variation, 86.8% had the following parameters:

$$\ln \mathrm{Pu} = 24.76 - 0.1187 \ln X - 3.615 \ln Y,$$

where Pu = Pu concentration (dis/min/g), X = distance east of asphalt pad centerline (m) and Y = distance south of asphalt pad centerline (m).

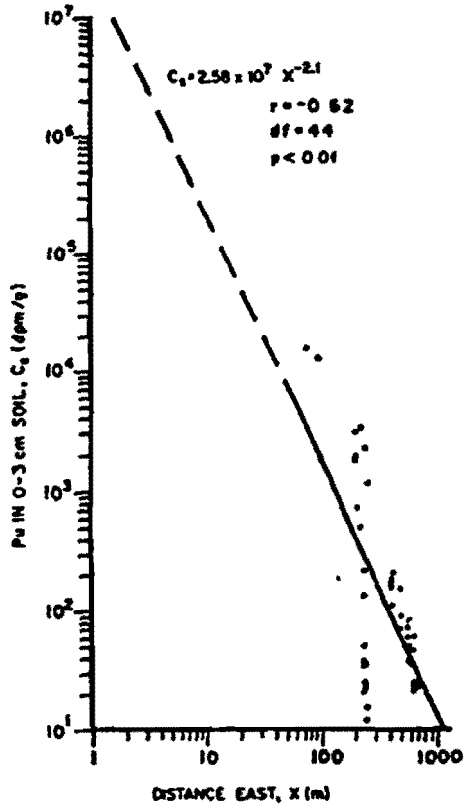

FIG 3. Plutonium concentration in 0–3-cm Rocky Flats Macroplot 1 soil as a function of distance east of the center of the asphalt oil barrel storage pad.

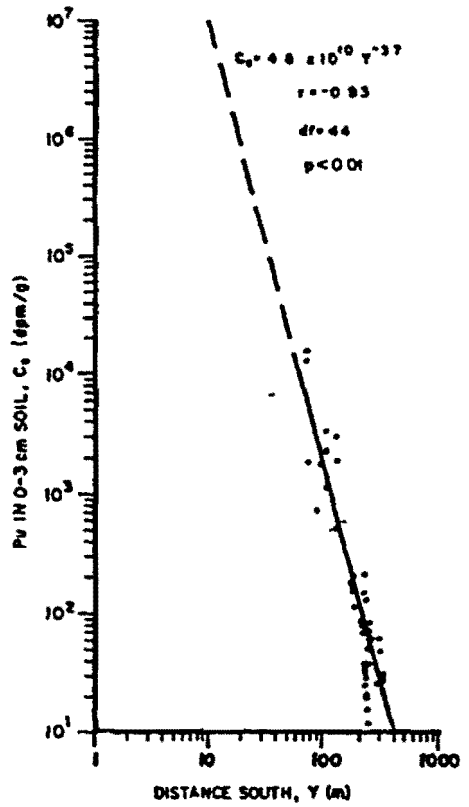

FIG 4 Plutonium concentration in 0–3-cm Rocky Flats Macroplot 1 soil as a function of distance south of the center of the asphalt oil barrel storage pad

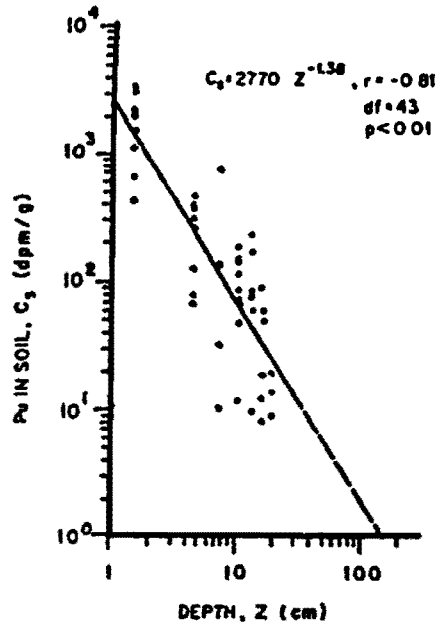

FIG 5 Plutonium concentration in Rocky Flats Macroplot 1 soil as a function of depth of sample. Sample concentrations corrected for distance east and south of center of asphalt oil barrel storage pad

Using this model, Pu concentrations of samples in the soil depth profile were adjusted to the expected concentration at a common location. The adjusted values were then regressed as a function of the sample depth (Fig. 5). The power function form of the relationship was significant ($P < 0.01$) and had the highest correlation of Pu concentration with depth of the models attempted.

The relationship of plutonium concentration in Macroplot 1 soil vs soil particle diameter (as represented by the opening of the final passage sieve) was examined for each depth using linear, exponential, and power function models. The following model most often gave significant results: ln Pu concentration = $b_0 + b_1$ ln diameter (Table 3). The steepest slope, at the 12–15-cm depth, was significantly different from the flattest slope, at the 3–6-cm level ($P < 0.05$). However, there seemed to be no clear-cut trend in slope of the Pu vs soil-particle size relationship with depth.

A tabulation of the sieve fraction data by size range and depth for both macroplots did not produce any particular pattern with either depth or particle size range Furthermore, regressions of fraction of total soil mass per sample as a function of depth were not significant for most sieve fractions.

Table 3 Regression parameters of soil plutonium concentration (Pu) dpm/g adjusted for the sample location on macroplot 1, as a function of soil particle diameter (D), cm, at various depths. The model used was $\ln Pu = b_0 + b_1 \ln D$

Depth (cm)	Intercept (b_0)	Slope (b_1)	Correlation coefficient (r)	Significant at $\alpha =$	n
0–3	5.62	−0.336	−0.312	0.01	72
3–6	4.40	−0.270	−0.291	0.05	69
6–9	1.69	−0.753	−0.471	0.001	50
9–12	2.40	−0.544	−0.564	0.001	69
12–15	1.47	−0.799	−0.719	0.001	52
15–18	0.583	−0.775	−0.706	0.001	47
18–21	0.375	−0.572	−0.358	—	22

DISCUSSION

A scenario of the contamination process based on these and other data is postulated The Pu-contaminated cutting oil, comparable to lightweight motor oil but often thinned by carbon tetrachloride, was stored in 55-gal barrels for up to 7 yr (1957–1964) Before placement in barrels, the oil was reportedly drained through 2–3-μm filters. Dilute hydrochloric acid formed by reaction of carbon tetrachloride and water may have led to the production of very low concentrations of plutonium chloride, a relatively soluble Pu compound (Cl76) Supporting this contention, a 0 01-μm filter removed only about 50% of the plutonium from similarly contaminated oil stored for shorter periods, indicating that much of the Pu was either monomeric or very small particles (Na76) However, during the long storage period, the Pu species remaining in the oil might have combined to form aggregates (Cl76) Unfortunately, the size and binding tenacity of these conglomerates, if formed, is unknown

Leakage from the barrels was most likely not large or fast at first, but may have become so with time. Contaminated oil was deposited onto the ground surface and stabilized the soil where plutonium became available for binding to soil particles Plutonium deposited as metal particles likely oxidized slowly at normal temperatures in the presence of air The resulting plutonium

oxide was relatively soluble in water compared to high-fired oxides but relatively insoluble in water compared to most metallic oxides. If plutonium chloride were deposited on the soil, it was likely hydrolyzed soon after first contact with water and eventually became oxidized. The solubility of these compounds was again probably low relative to most compounds but greater than the high-fired oxides (Cl76).

It is probable that all PuO_2 particles, or molecules, eventually became attached to soil particles. Most likely, this attachment took the form of easily erodible, agglomerated particles, each containing numerous PuO_2 and soil particles

Redistribution of contaminated soil from the various drum leakage events was probably a relatively short or erratic process occurring with surface disturbance and high winds, as indicated by the S-8 air sampler data The regressions of Pu concentration as a function of X or Y distance and the multiple regression including the same data indicated that the slope associated with the Y (south) term was steeper than the slope of the X (east) variable. Since the X term is primarily in the direction of the predominant wind and the Y direction is subjected mostly to downward slope, wind seems to be the more likely transport force.

The S-8 air data, coupled with prevailing wind information, and the regression of plutonium concentration vs distances east and south of the source are strong evidence that wind was the primary mode of plutonium dispersion from the oil barrel storage area to the study macroplots.

In time, dispersed plutonium-contaminated soil particles no longer were significantly redistributed by wind. Wind, precipitation, and gravity may have caused particles to migrate from exposed surfaces downward into the soil, where they were sheltered by larger particles, litter, or vegetation Soil–plutonium particles may have gradually broken down by natural weathering processes, allowing the constituents to disperse on a microscale (i e on the order of a few centimeters). This concept is supported by results of autoradiographic studies of soil from Macroplot 1 (Mc78) that indicated that most contaminated particles are very small or single particles. Furthermore, this process is compatible with the high degree of spatial variability observed

In summary, the major facets of the scenario include· (1) either before or shortly after leakage onto the ground surface, the Pu contaminant was in the form of an oxide; (2) the Pu oxide became attached to soil particles, (3) gusty winds combined with periods of surface disturbance heterogeneously redistributed the particles to the east and southeast of the barrel storage area; and (4) the soil–Pu particles were eventually broken down by weathering and were dispersed laterally and downward into the soil profile

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REFERENCES

An76 Anonymous, 1976, Rocky Flats 1975 Annual Weather Summary, Unpublished. Environmental Sciences, Rocky Flats Plant, Rockwell International, Golden, CO.

Ce69 Cember H., 1969, *Introduction to Health Physics* (New York· Pergamon Press)

Cl76 Cleveland J M, 1976, Personal communication, Environmental Studies, Rocky Flats Plant, Rockwell International, Golden, CO.

Dr66 Draper N. R and Smith H, 1966, *Applied Regression Analysis*, (New York· Jonn Wiley)

Hu76 Hunt D C., 1976, Personal communication, Environmental Sciences, Rocky Flats Plant, Rockwell International, Golden, CO.

Jo76 Johnson C J., Tidball R. R and Severson R. C, 1976, "Plutonium Hazard in Respirable Dust on the Surface of Soil", *Science* 193, 488

Kr70 Krey P. W and Hardy E P., 1970, Plutonium in Soil Around the Rocky Flats Plant, USAEC Report HASL-235 (New York· USAEC Health and Safety Laboratory)

Li76 Little C A, 1976, Plutonium in Grassland at Rocky Flats, Ph D Thesis, Colorado State University, Fort Collins

Ma70 Martell E A, Goldan P A, Kraushaar J

J., Shea D. W. and Williams R. H., 1970, "Fire Damage", *Environment* 12, 15.

Mc78 McDowell L. M. and Whicker F. W, 1978, "Size Characteristics of Plutonium Particles in Rocky Flats Soil", *Health Phys* (to be published)

Na76 Navratil J. D and Baldwin C. E, 1976, Recovery Studies for Plutonium Machining Oil Coolant, Draft of ERDA Report RFP-2579 Rockwell International, Golden, CO.

Pi75 Pinder J. E., III and Smith M H, 1975, "Frequency Distributions of Radiocesium Concentrations in Soil and Biota", in *Mineral Cycling in Southeastern Ecosystems*, pp 107–125 (Edited by Howell F. G., Gentry J. B. and Smith M. H) USERDA Symposium Series, CONF-740513.

Po72 Poet S. E. and Martell E A, 1972, "Plutonium-239 and Americium-241 Contamination in the Denver Area", *Health Phys.* 23, 537.

Sh71 Shapley D., 1971, "Rocky Flats: Credibility Gap Widens on Plutonium Plant Safety", *Science* 174, 569.

Si56 Siegel S., 1956, *Nonparametric Statistics for the Behavioral Sciences* (New York· McGraw-Hill)

Si69 Sill C. W. and Williams R C, 1969, "Radiochemical Determinations of Uranium and the Transuranium Elements in Process Solutions and Environmental Samples", *Analyt Chem.* 41, 1624

Sn67 Snedecor G W. and Cochran W G, 1967, *Statistical Methods*, (Ames, IA Iowa State University Press)

We71 Wessman W A, Major W. J, Lee K D and Leventhal L., 1971, "Commonality in Water, Soil, Air Vegetation, and Biological Sample Analysis for Plutonium", in. *Proceedings of Environmental Plutonium Symposium held at LASL, August 4–5*, 1971, pp 73–79, (Edited by Fowler E B, Henderson R W and Milligan M F) (Los Alamos, NM Los Alamos Scientific Laboratory)

We74 Weber W A, Kunkel G and Schultz L, 1974, A Botanical Inventory of the Rocky Flats AEC Site Final Report, USAEC Report COO-2371-2 (Boulder, CO University of Colorado)

Wh66 Whicker F W, Farris G C. and Dahl A H, 1966, "Concentration Patterns of ^{90}Sr, ^{137}Cs, and ^{131}I in a Wild Deer Population and Environment", in *Radioecological Concentration Processes*, pp 621–633, (Edited by Aberg B and Hungate F P) (New York Pergamon Press)

Wh73 Whicker F W, 1973, Radioecology of Some Natural Organisms and Systems in Colorado, USAEC Report COO-1156-63 (Fort Collins, CO Colorado State University)

Statistical Confidence as it Relates to Soil Sampling at Rocky Flats

Rik Getty, Technical Adviser, Rocky Flats Coalition of Local Governments (RFCLOG)

Introduction

The Board of Directors of RFCLOG requested that I author a short discussion for the general public on what statistical confidence means relative to soil sampling at Rocky Flats. Over the course of many briefings by the Department of Energy (DOE) and their primary clean-up contractor, Kaiser-Hill (K-H), to the RFCLOG Board and general public, various statistical confidence levels have been mentioned. Unless one is quite familiar with basic statistical sampling methods it can be quite a daunting task to understand what these various types of statistical methods actually mean in lay terms.

To begin this discussion I thought I would start with a brief background on how soil sampling methodology was developed for Rocky Flats and then have a short discussion of sampling statistics in general. Finally I would transition into real examples used by DOE and K-H to describe statistical confidence in their soil sampling.

Rocky Flats Soil Sampling Methodology

The soil sampling methodology used at Rocky Flats is a combination of various techniques that are in widespread use around the world. In the U.S., CERCLA sites like Rocky Flats use many of the guidelines established by the U.S. EPA for soil sampling. In addition, geostatistical sampling methods developed for different geological-based industries are also used for soil sampling. The site (DOE, K-H, and their subcontractors) formed a working group with regulatory staff from the EPA and CDPHE to develop the Sampling & Analysis Plans (SAPs) for the Buffer Zone (most of which is slated to become part of the Wildlife Refuge) and the Industrial Area (all of which will remain as DOE-retained land).

The working group selected different soil sampling strategies depending on what existing characterization data was available for a given location. For example, areas where there was known contamination due to releases of:

- Radionuclides (primarily plutonium, americium, and uranium isotopes);
- volatile organic compounds (VOCs; primarily chlorinated solvents);
- semivolatile organic compounds (SVOCs; liquid chemicals that don't evaporate readily like machining oils, polychlorinated biphenyls);
- hazardous metals (e.g., lead, cadmium, chromium, etc.); and,
- other regulatory chemicals such as nitrates.

Generally speaking the vast majority of areas contaminated with the contaminant species listed above were located in the Industrial Area. Due to their known locations of contamination, targeted soil sampling was selected as the appropriate sampling methodology. Targeted sampling involves determining the general contamination levels within a known area.

Areas where there was no indication of prior contamination, primarily in the Buffer Zone, utilized a statistical grid sampling methodology. The grid spacing for sample locations was determined by the working group based on the required statistical confidence. Typically a 90% confidence was used to characterize soils in the Buffer Zone (I will discuss the 90% confidence later in this briefing).

Some areas such as the 903 Lip Area required both targeted and grid spacing soil sampling per the working group requirements. The 903 Lip Area was the largest (36 acres) remedial project at

the site. It is considered part of the Buffer Zone but will remain as part of the DOE-retained land and will not be transferred to the Wildlife Refuge. I will present soil sampling data on the 903 Lip Area at the end of this briefing.

Basic Statistical Sampling

When one is trying to understand statistical sampling applications there are a few basic parameters to define (after that statistics delves into very complex scenarios). However for the sake of this briefing I want to confine my explanations of statistical sampling to a basic level.

Many things exhibit properties of statistics in nature and the everyday world. I'm sure the reader of this briefing has some personal experiences that delve into aspects of statistics. Examples could be the outcome of simple coin tosses, gambling experiences, voter survey results, or perhaps even some who utilize more complicated statistics as part of their work or hobbies. Whatever the case, statistics are a very useful tool in a wide variety of applications.

In this briefing we are interested in how statistics are used for soil sampling at the site. Sampling of soil generates a collection of data that must be interpreted. Suppose you have a large number of results (a population) for a given analysis. The simplest statistical model for a population of results is that of a "normal" or Gaussian (Gauss was a famous statistician) distribution of results. The normal distribution of results exhibits behavior like that shown in Figure 1 (page 4). The x-axis represents the different range of values of the results. The y-axis represents the relative frequency of the values. In other words the more results there are with the same value the higher the relative frequency. Normal sample distributions are centered around a "central" value known as the population mean (average value). The shape of the normal distribution curve tails off to the left and right of the mean value. As one follows the curve to the right of the mean, the values increase (+) and their relative frequency decreases. As one follows the curve to the left the values decrease (-) and their relative frequency decreases. The total area under the curve, including the "wing" sections to the left and right represent the total sample population.

Not all sample populations exhibit a normal distribution. Figure 2 (page 4) shows a normal distribution as well as a population which has the same mean but exhibits different +/- ranges. There are several other types of sample distributions such as "log-normal" distributions. I will not delve into their behavior but instead focus on normal distributions.

Figure 3 (page 5) is a normal distribution with 90% and 95% confidence ranges added for illustrative purposes. If one were to take the total area under the curve between the two 90% values then that area represents 90% of the sample population. It also tells you the range of the sample values for 90% of the population. Likewise the two 95% values represent 95% of the sample population.

903 Lip Area Example

As previously mentioned, the 903 Lip Area remediation project was the largest environmental restoration project at the site encompassing 36 acres. The regulator-approved (EPA & CDPHE) Buffer Zone SAP specified a combination of targeted and grid spacing soil samples for the 903 Lip Area. The remediation required the site to remove contaminated soil which exceeded the Wildlife Refuge Worker Action Level of 50 picocuries of plutonium activity per gram of soil (50 pCi/g). The site used a geostatistical technique known as probability Krieging to determine the boundaries of the remediation project. The stated objective of the probability Krieging was to have a 90% level of confidence that all of the contaminated areas in the 903 Lip Area which exceeded the 50 pCi/g Pu were contained within the Krieging boundary. Of course that objective

means there is a 10% probability that there were areas which exceeded the 50 pCi/g limit outside the Krieging boundary.

The 903 Lip Area remediation was broken down into small sections of remediation work. Contaminated soil which exceeded the 50 pCi/g was removed from a section and then confirmation samples were taken to verify that the section was below the 50 pCi/g limit. Many times, the confirmation samples failed (exceeded 50 pCi/g) and more contaminated soil had to be removed. This required additional confirmation samples until the section met the requirements. Hundreds of confirmation samples were taken by the site during this remediation project. After completion, the mean value for remaining plutonium contamination in the remediated sections was 14 pCi/g.

Figure 4 (page 5) is an example of one way the remaining contamination in the 903 Lip Area sections can be viewed. This depiction may not be accurate but is for illustrative purposes only. The site's confirmation sampling and probability Krieging specified a 90% confidence level. The distribution curve in Figure 4 is not a normal distribution in the sense that the curve is shifted somewhat to the right. This shift is to reflect the fact that there is a probability of some of the soils exceeding 50 pCi/g. The site's confirmation sampling concluded there were no areas in the remediated 903 Lip Area which exceeded 50 pCi/g plutonium at the 90% confidence level.

After the remediation was completed, DOE retained an independent contractor (Oak Ridge Institute for Science and Education, a.k.a. ORISE) to verify the remaining soil conditions in the 903 Lip Area remediation. ORISE's examined two areas or survey units each about 45 meters by 45 meters (2025 square meters). The initial soil samples from these two survey units was in close agreement with the site's values. None of the ORISE samples exceeded 50 pCi/g plutonium. ORISE specified a 95% confidence in their sample results. After ORISEZ performed the confirmation sampling additional "hand scans" were performed with file-portable instrumentation. Using this technique ORISE found several "hotspots" which exceeded the 50 pCi/g plutonium. These areas were further characterized by the site and ORISE and were subsequently remediated. The total area of the hotspots was only 1.6% of the total area of the 2 survey units. So in practical terms, the "discovery" of the hotspots should not come as a surprise since the site's stated confidence in detecting hotspots was 90%. ORISE's report to the site on their verification activities stated that the presence of hotspots in the 2 survey units are likely representatative of the remaining 903 Lip Area.

Closing Remarks

I hope this briefing has not been overly tedious and confusing. I had a challenging time deciding how to approach the briefing structure.

FIGURE 1. "NORMAL" OR GAUSSIAN SAMPLE DISTRIBUTION

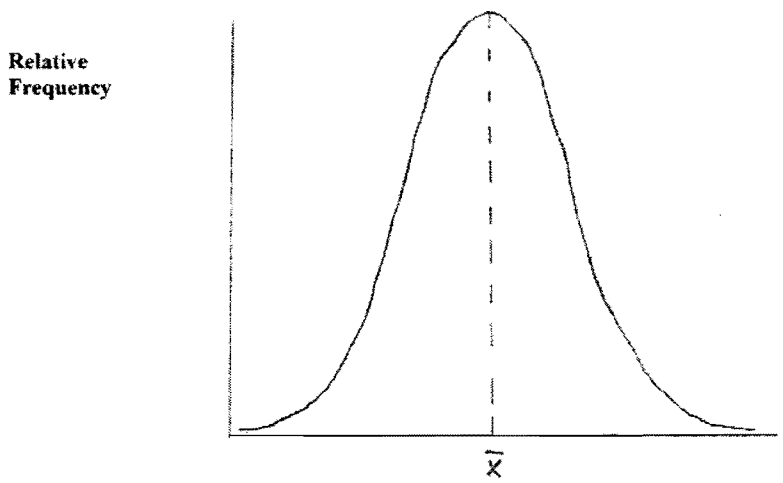


FIGURE 2. TWO DIFFERENT SAMPLE DISTRIBUTIONS WITH SAME MEAN

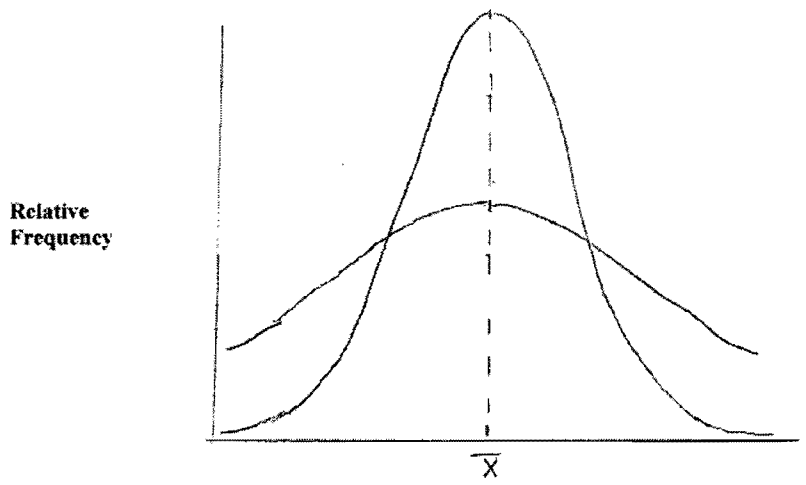


FIGURE 3. NORMAL DISTRIBUTION WITH 90% & 95% CONFIDENCE

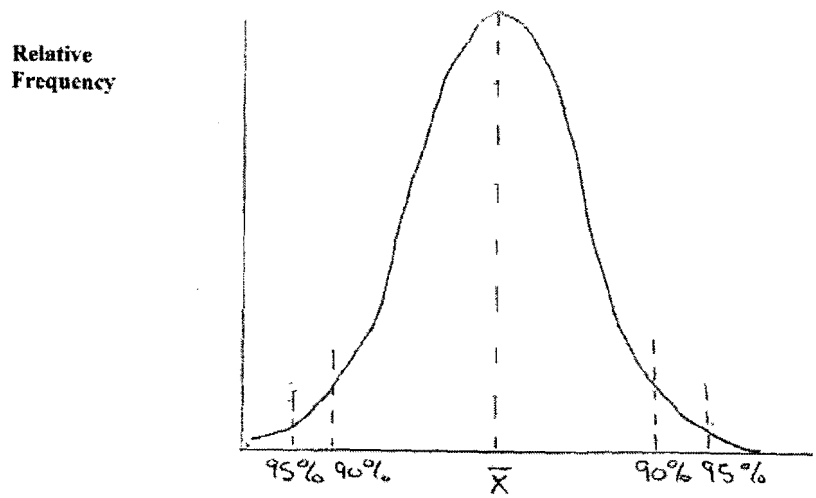
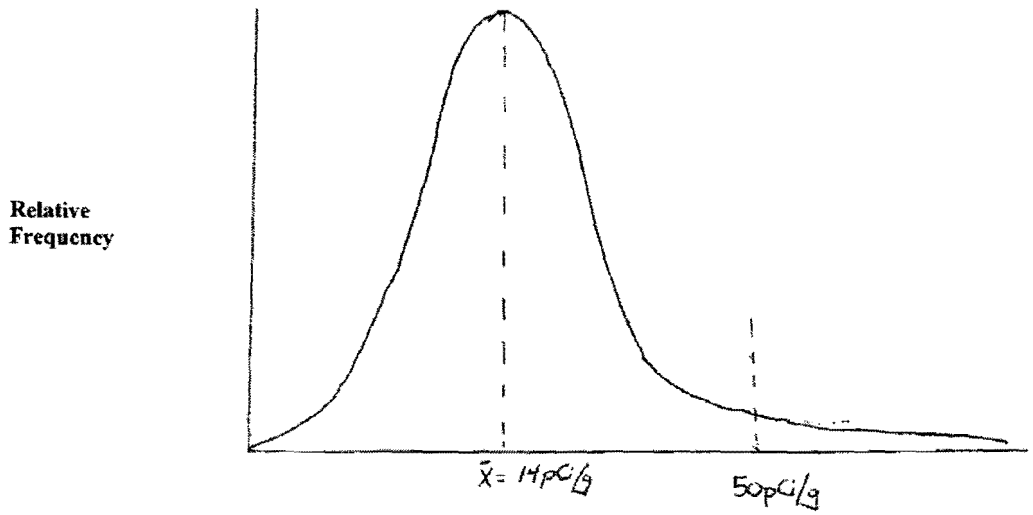


FIGURE 4. EXAMPLE OF REMAINING Pu CONTAMINATION IN 903 LIP AREA



DOE AMP Proposal

- Cover memo
- AMP meeting notes – 2/3/11 meeting
- AMP meeting notes – 2/10/11 meeting
- AMP meeting notes – 2/17/11 meeting
- AMP meeting notes – 3/3/11 meeting
- Broomfield 2/15/11 proposed AMP language
- Broomfield 3/2/11 proposed AMP language
- Broomfield 2/1/11 letter to CDPHE
- CDPHE reply to Broomfield's 2/1/11 letter